



HYDROBALLISTICS

Development, Theory & Some Test Results



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MH-60S With RAMICS Installed



Target Reacquisition Using LIDAR
MK 44 Bushmaster II Chain Gun
MK 258 Hydroballistic Ammo

What Is Hydroballistics?

- The Study Or Design Of Objects That Have Momentum Underwater
 - Fully Wetted, Cavitating, & Supercavitating
- Key Parameters Are Drag, Stability & Control, & Structural Integrity
- Water Entry Of Projectile Considerations:
 - Air Entrainment (Not A Great Factor In Supercavitating Bodies)
 - Water Impact Loads

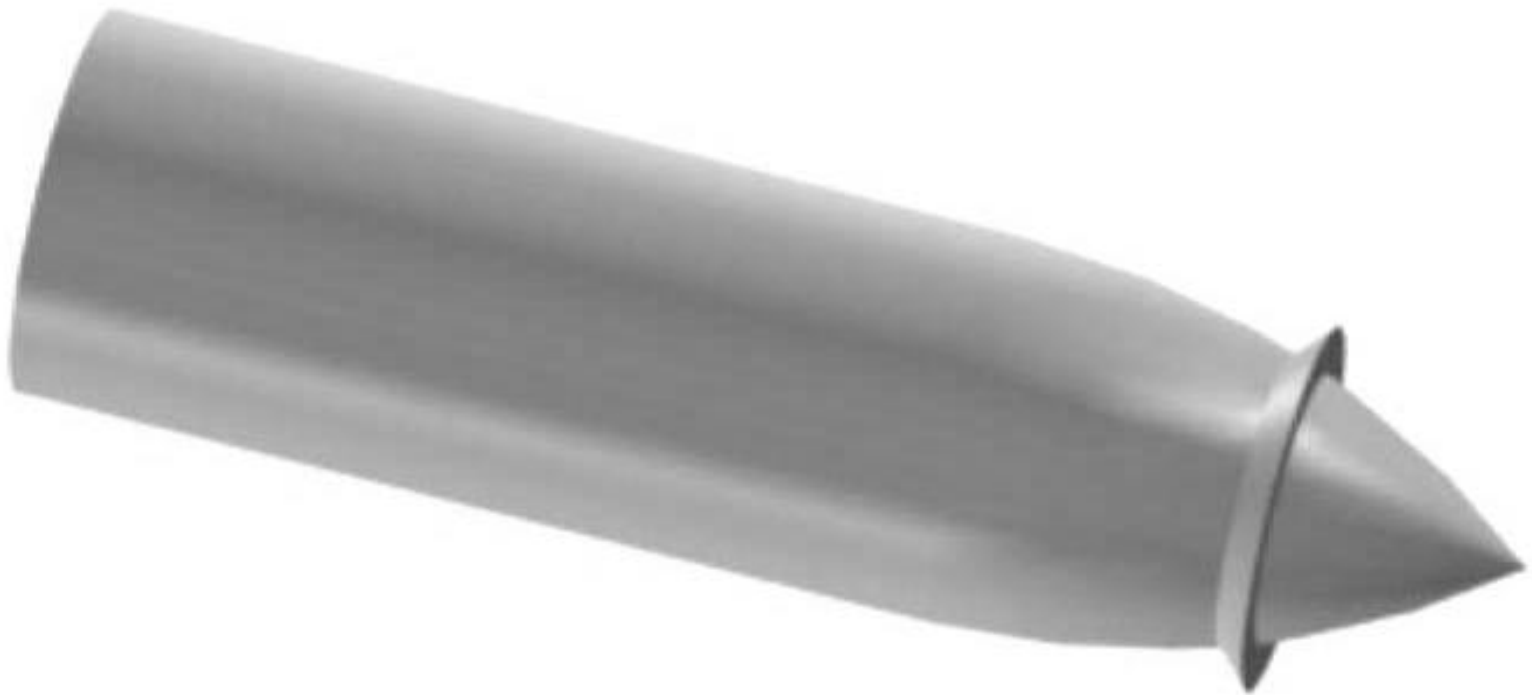
Hydroballistics Of Supercavitating Water Entry Projectiles

- Spin-Stabilized (In-Air) Projectiles Are Not Good Performers
 - Conventional Bullets Tumble Quickly After Water Entry
- Mass Stabilized Projectiles Are Successful
- High L/D Projectiles Have Consistently Proven Superior Hydroballistic Performance
 - Stabilizing Empennage Shared For Both Air And Water

History Of Water-Entry & Supercavitation Work

- 1870: Franco-Prussian War - Kopfring Developed
- 1908: “Study Of Splashes” - First Water-Entry Photos (Worthington)
- WW I: Edison Proposed Pagoda Head For Water-Entry Device
- WW II: Torpedoes, Mines, and Water-Entry Bombs
- Post WW II: Numerous Water-Entry/Cavitation Studies Of Rockets & Gun-Launched Projectiles
- 1970’s To Present: Exploit Supercavitation (Drag Reduction)

Kopfring Device



25mm WHITE OAK DEVELOPMENT (1995-1996) ONR Sponsor

Series I: Adapt Finned Long-Rods (U. S. Army 25mm M919 APFSDS-T); 9 Shots – Blunt Nose Proved Successful With Fins

Series II: Optimize Design (Reduce Nose Flat, Lengthen Nose & Increase Material Strength); 15 Shots

Series III: Introduced Carbide Nose Insert; Last Shot Established Record For Water Vehicles At 4300 ft/sec; 21 Shots

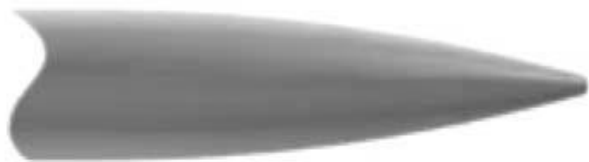
Hydroballistic Nose Shapes Tested At White Oak – Series I



Blunt Nose



Conical Nose



Power Law Nose

Refinement Of The Blunt Nose At White Oak – Series II & III



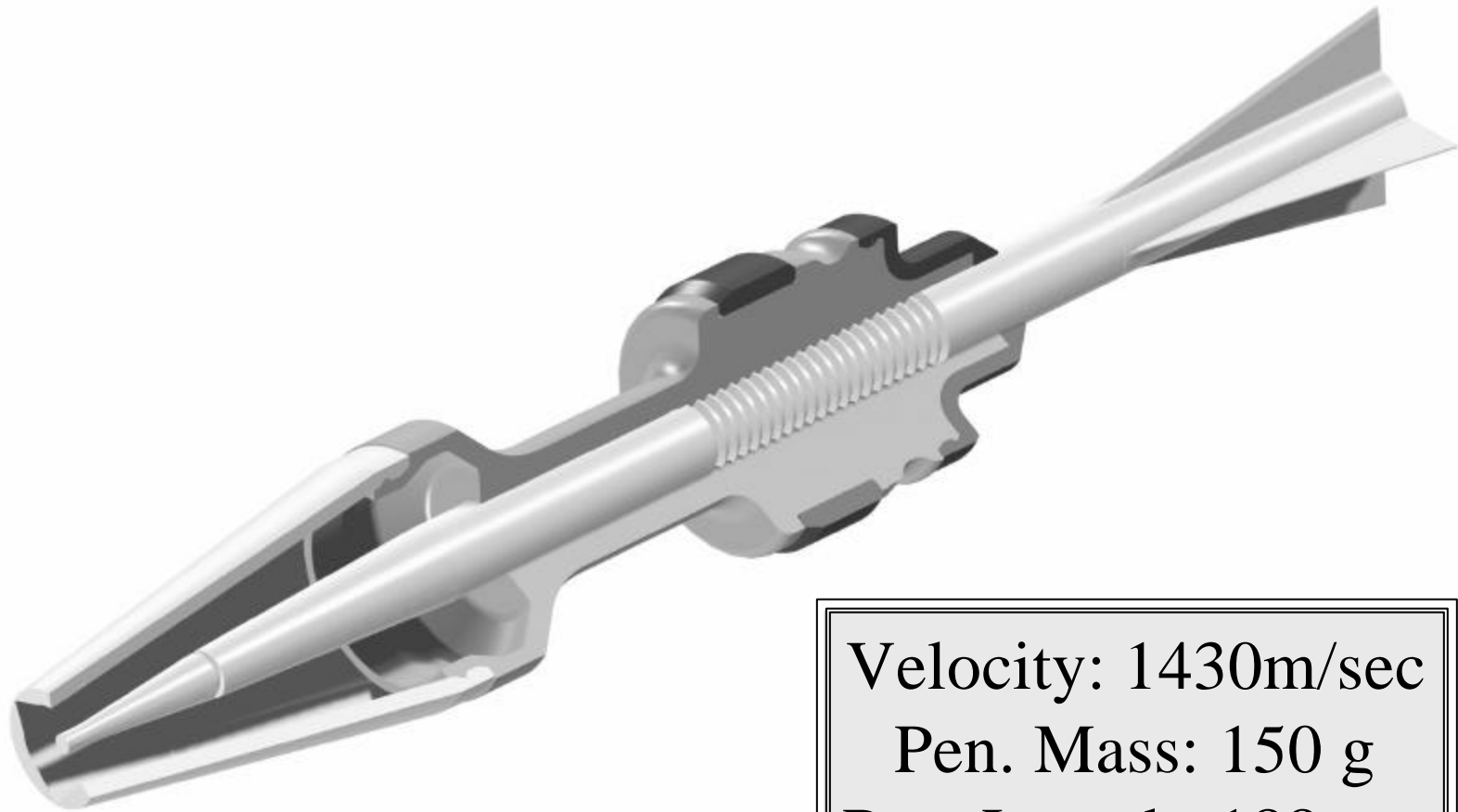
Generation I



Generation II

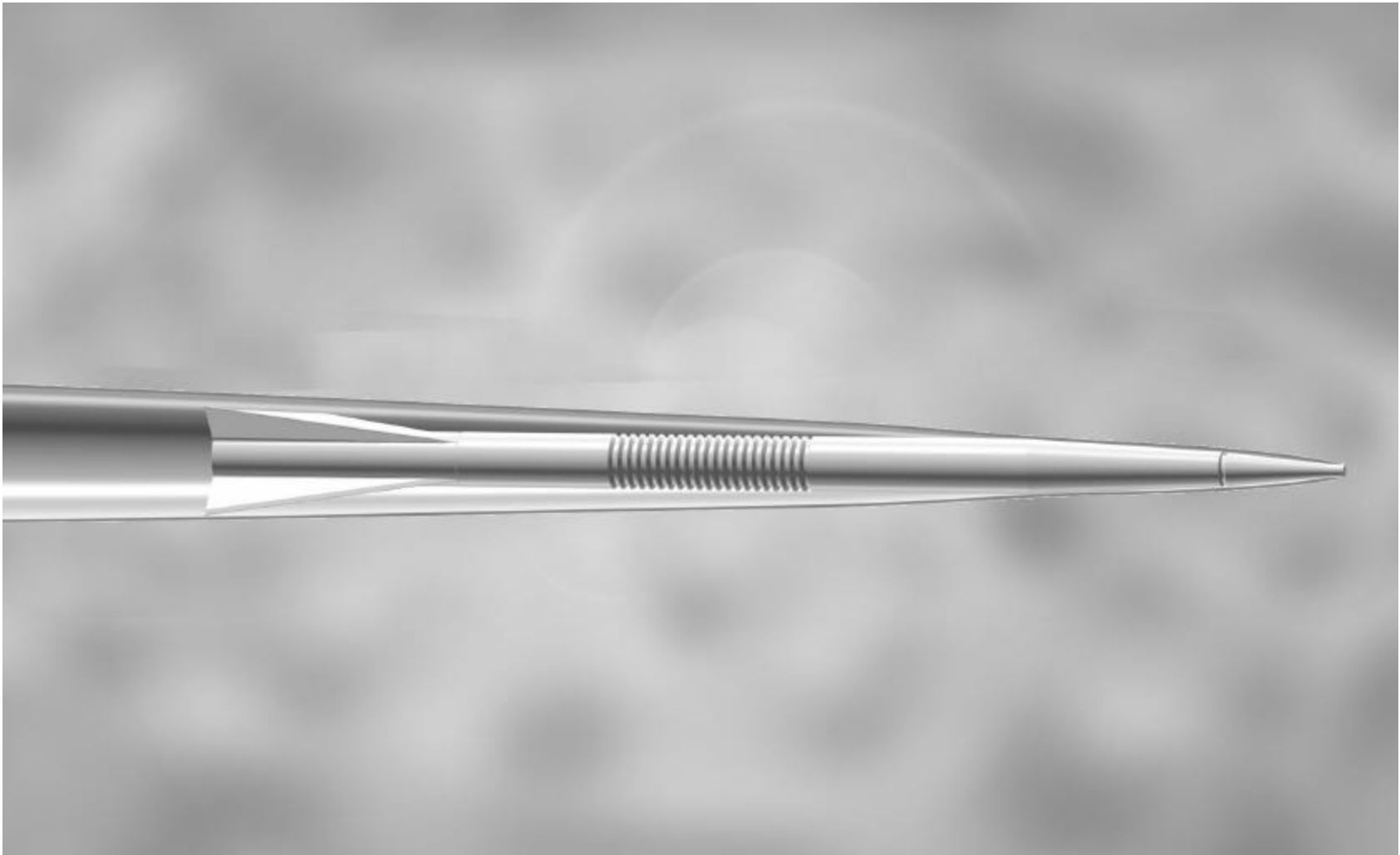


**Generation III
(Carbide Insert)**



Generation IV:
MK 258 Mod ?

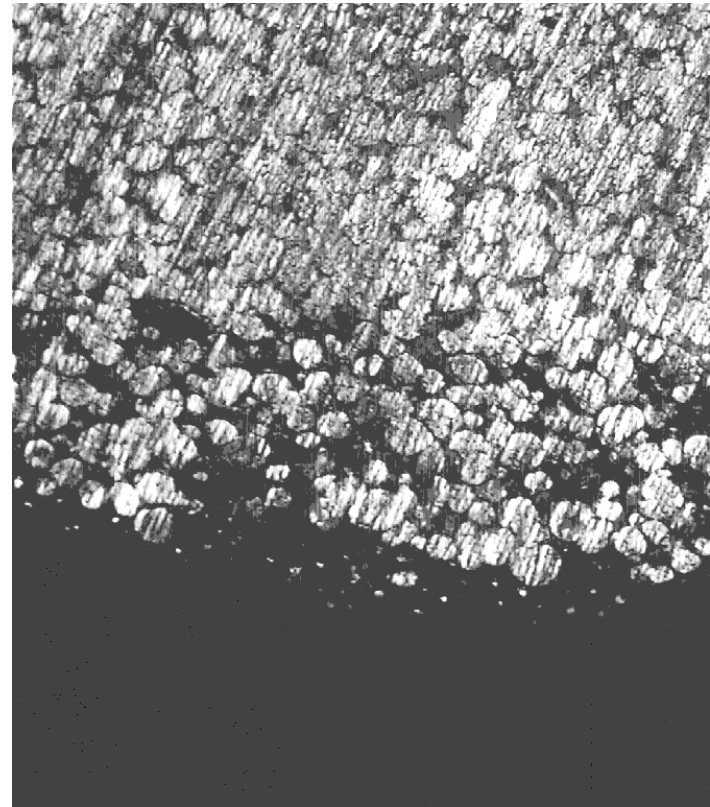
Velocity: 1430m/sec
Pen. Mass: 150 g
Pen. Length: 188mm
Pen. Dia: 9mm
Nose Dia: 2.3mm



Cavity Equation: $y = \frac{d}{2} \sqrt{(kx/d) + 1}$

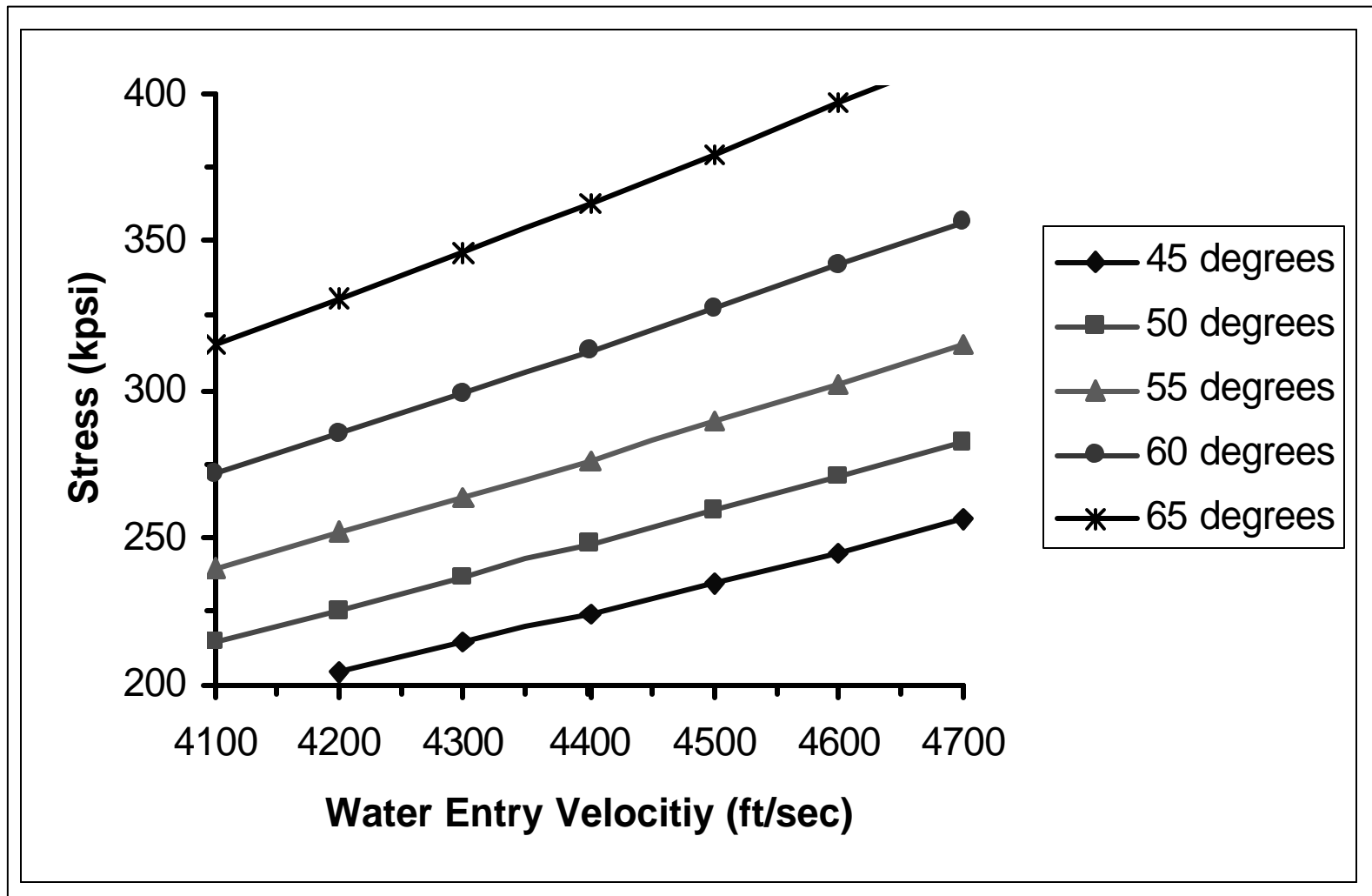
Water Impact Loads

- Theoretical Formula:
$$C_d^* = 0.79 + 0.93 \tan(\alpha)$$
- Stress At *Preferred* Impact Angle (60°) Can Climb To Over 300,000 psi
- Carbide Tips Successfully Tested (420,000 psi Strength)
- Successful Tests At 45° Exceeded Material Strength
 - Bow Shock May Mitigate Impact Load



Shot #8494: 3800 ft/sec; Mat. Limit – 3700 ft/sec 90x Magnification

Theoretical Water Entry Loads



(HYDRO) DRAG COEFFICIENT

- Same Principle As Aerodynamic Drag
- Instrumentation provides:
 - Water Impact Velocity, V_0
 - Trajectory Time, T

$$b = \frac{W}{C_d A}$$

$$T = \frac{2b}{rV_0} e^{\frac{rS}{2b}} - 1$$

$$V = V_0 e^{-\frac{rS}{2b}}$$

Known

W: Weight

A: Reference Area

S: Length

**HYDROBALLISTIC TEST SERIES I & II
ABERDEEN TEST CENTER
BRIAR POINT TEST POND
APRIL & AUGUST to OCTOBER 2000**

OBJECTIVES

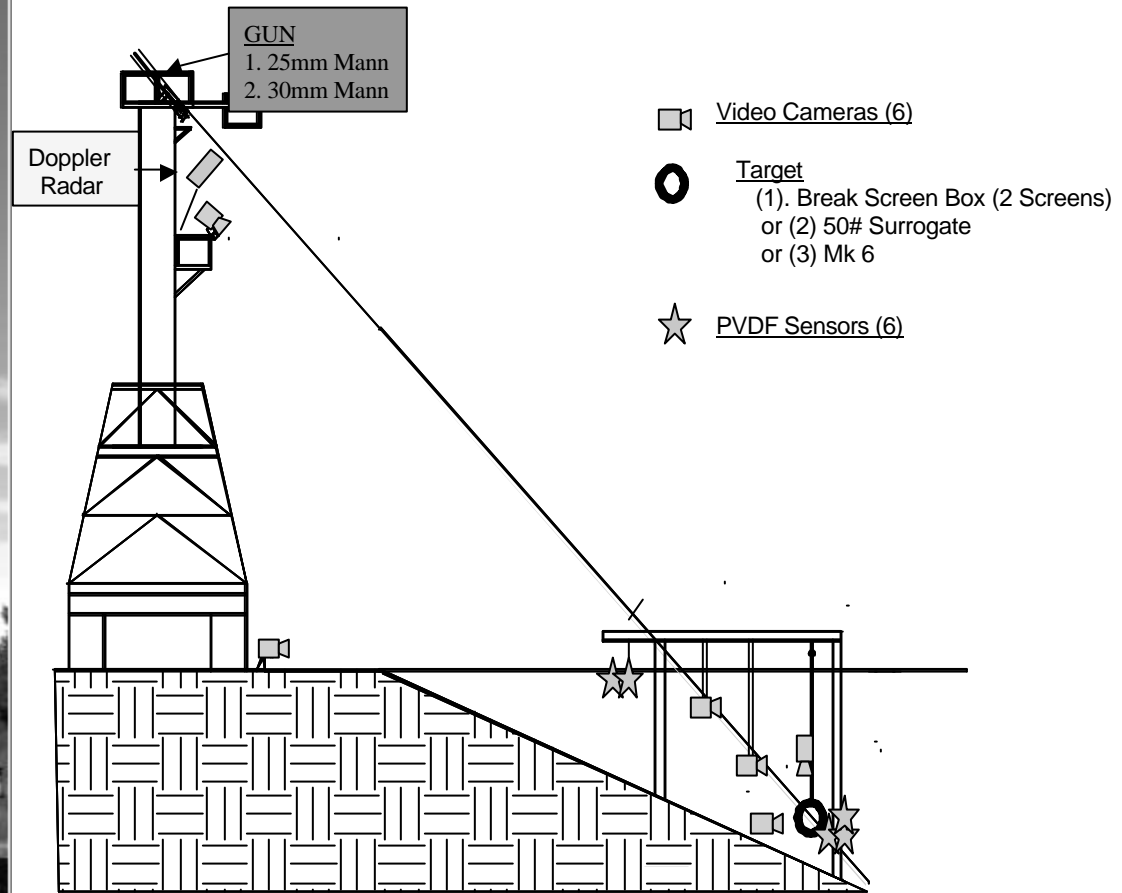
VERIFY PERFORMANCE OF 25MM

EVALUATE PERFORMANCE OF 30MM

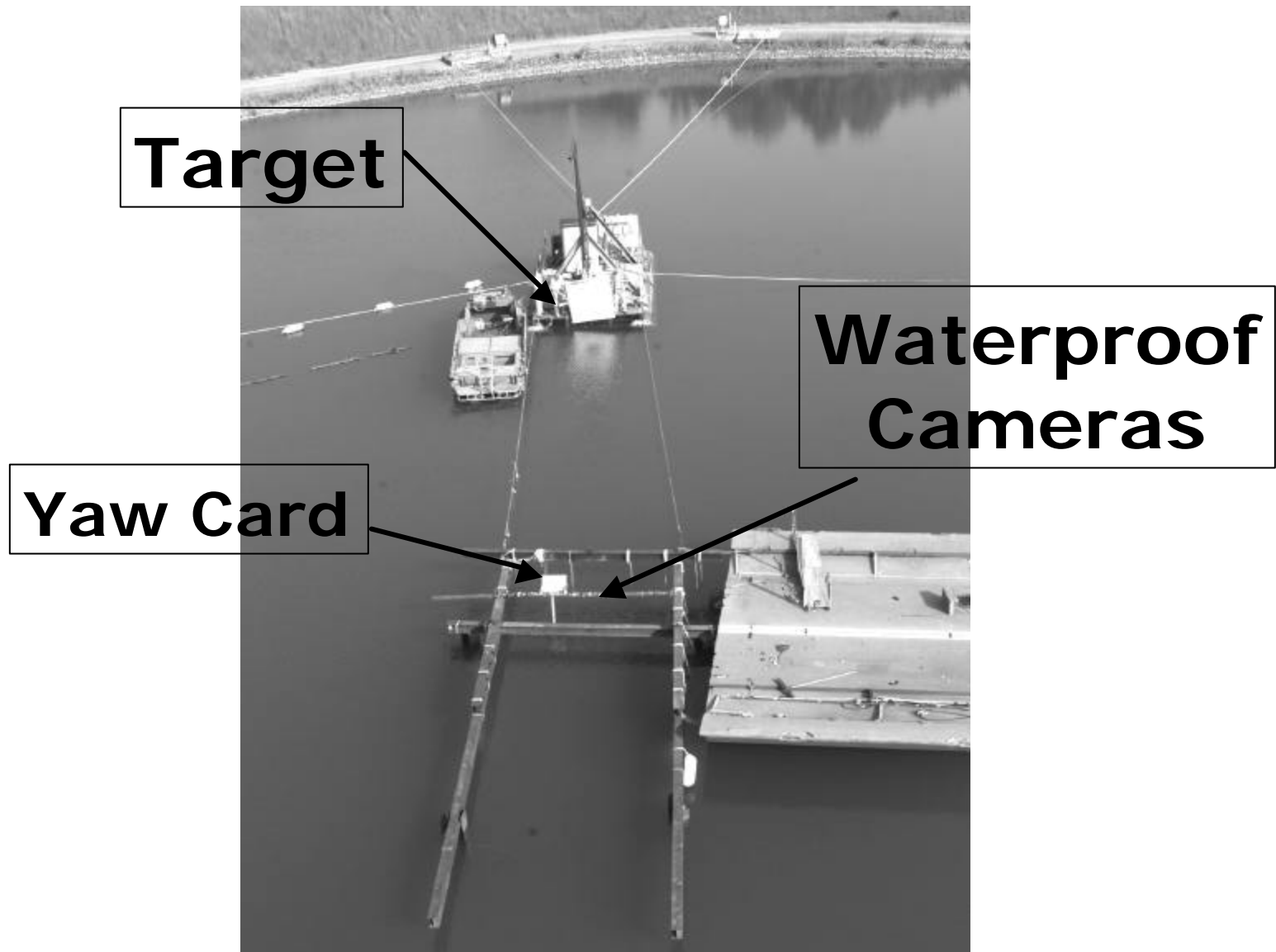
DEMONSTRATE UNDERWATER LETHALITY

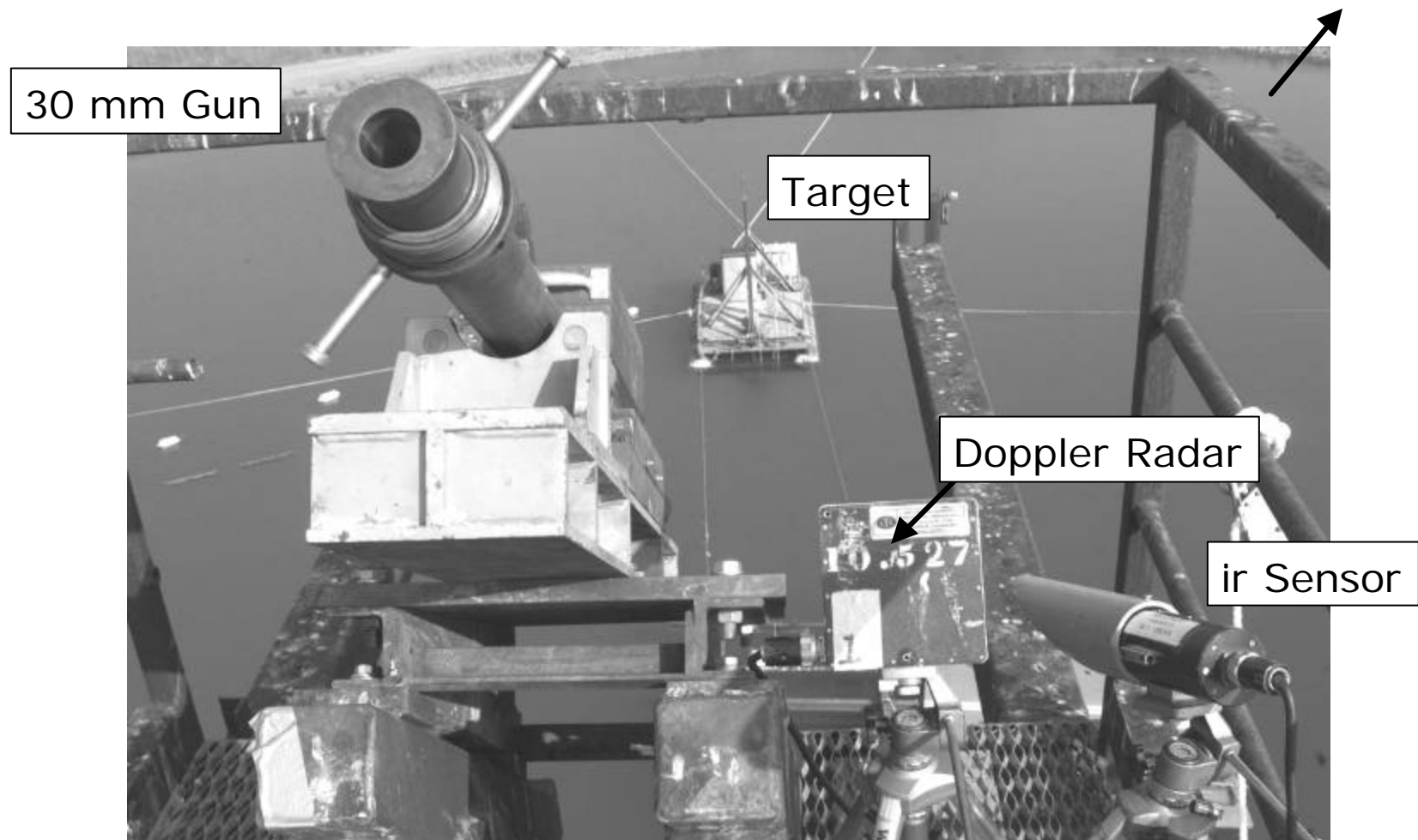
Hydroballistic Test Peculiarities

- Target “Sighting”
 - Land Based Surveying + Diligent Positioning
- Test Limitations
 - Limited Air Flight; Limited Water Depth
 - Underwater Cameras & Clarity Changes
 - Difficult To Measure Velocity
- Compounded Safety Considerations
 - Gun On Tower & Target In Water

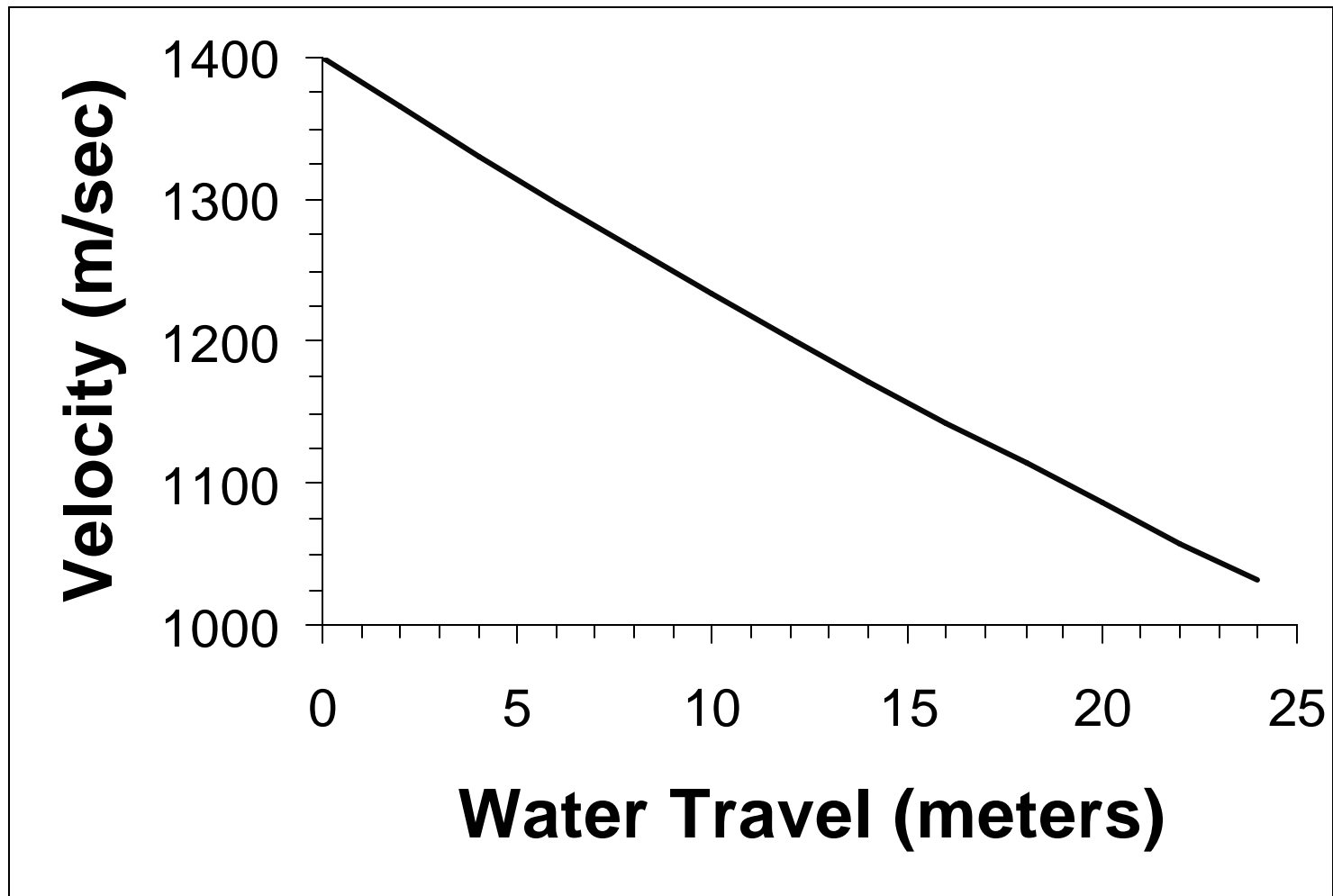


Briar Point Test Site

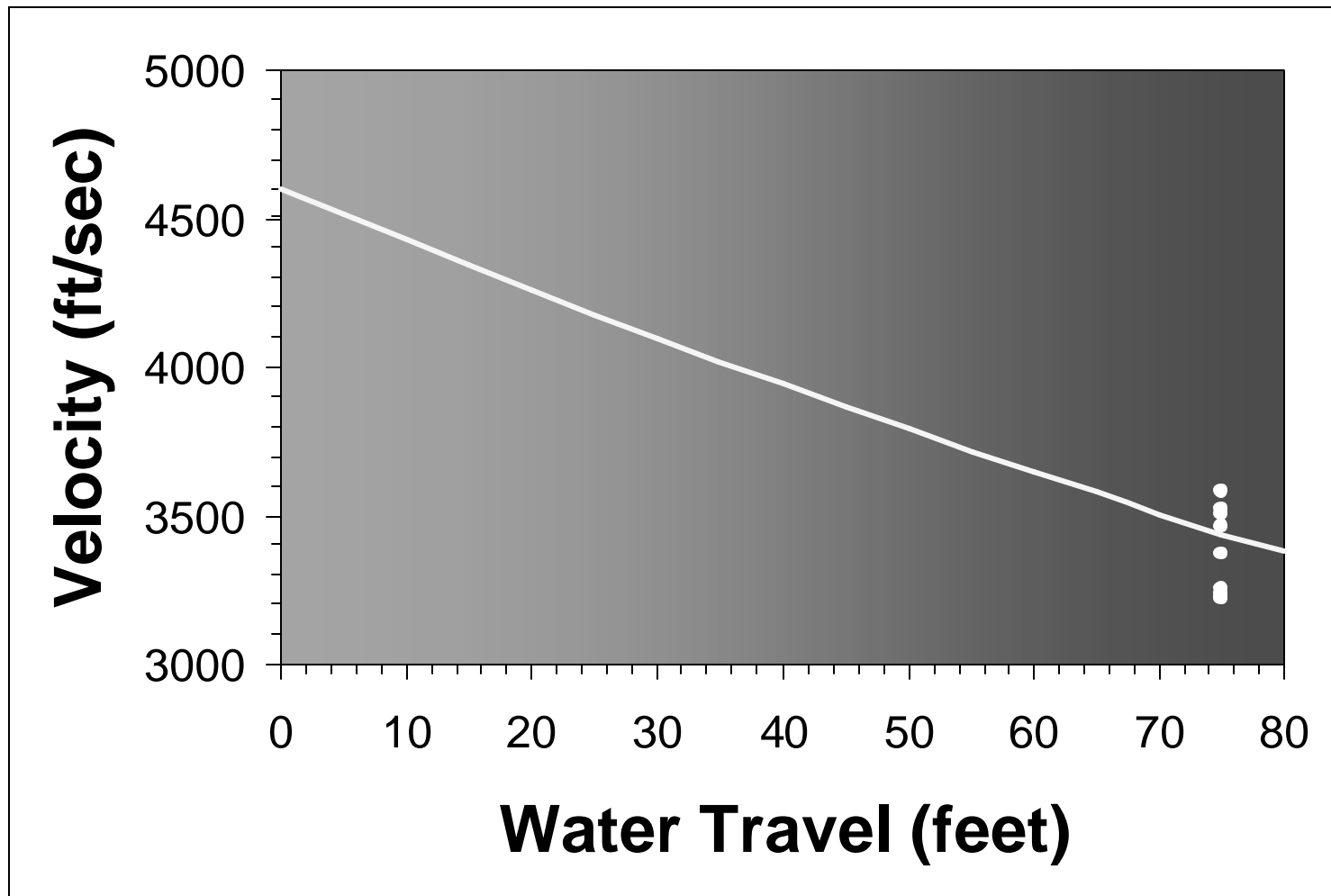


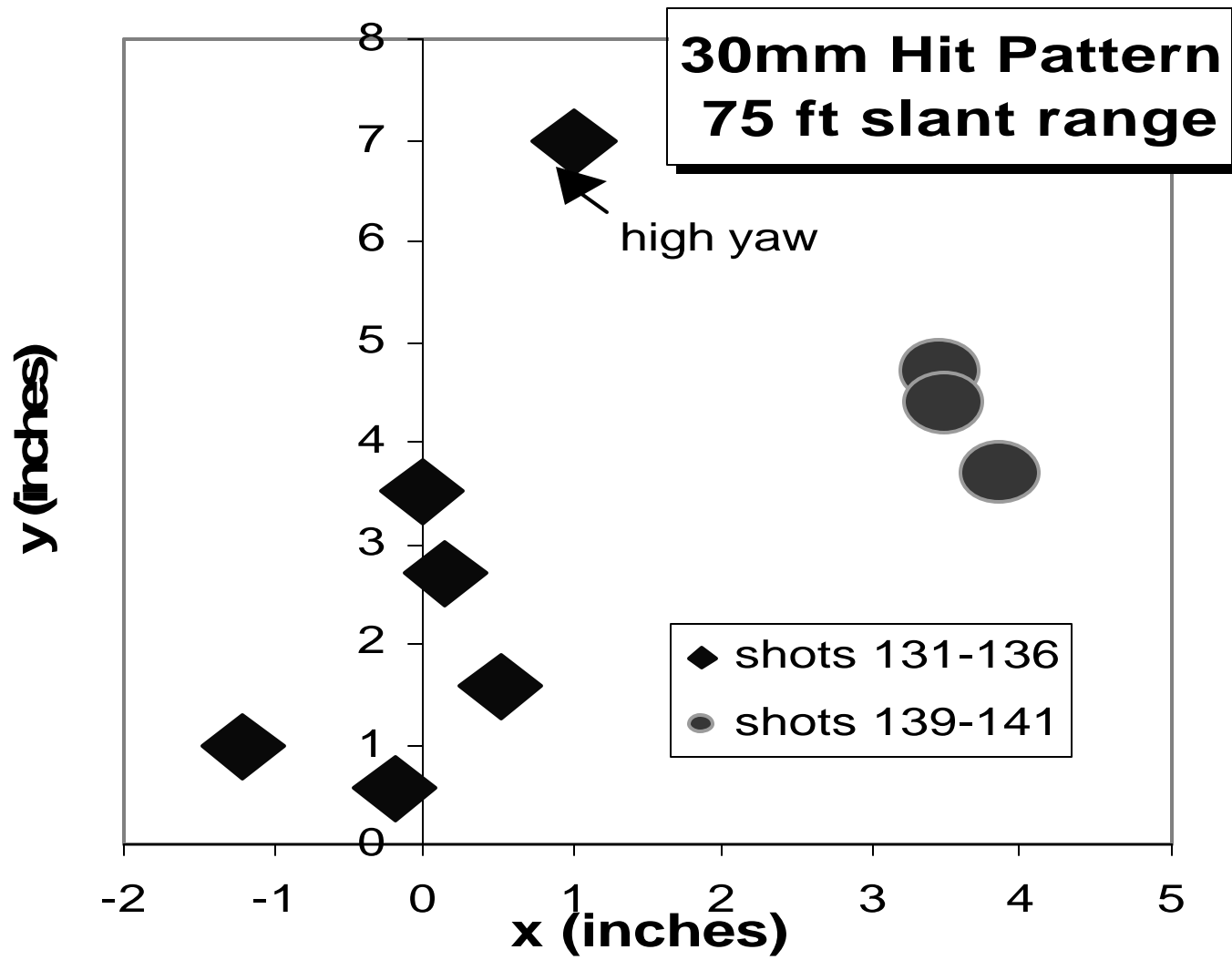


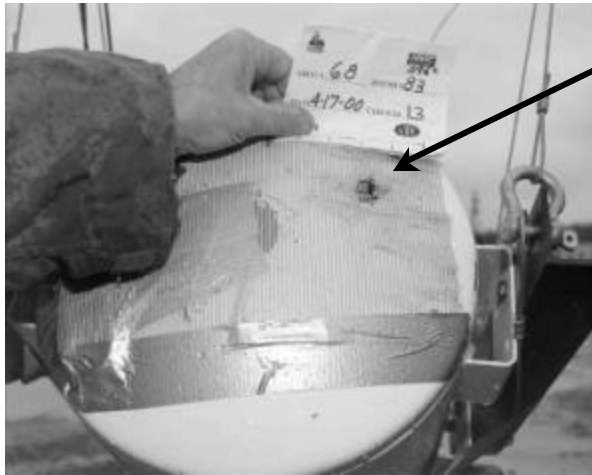
30mm MK 258 Hydro Performance



30mm MK 258 Hydro Performance







Entrance hole



30mm

1330 m/sec Water Entry

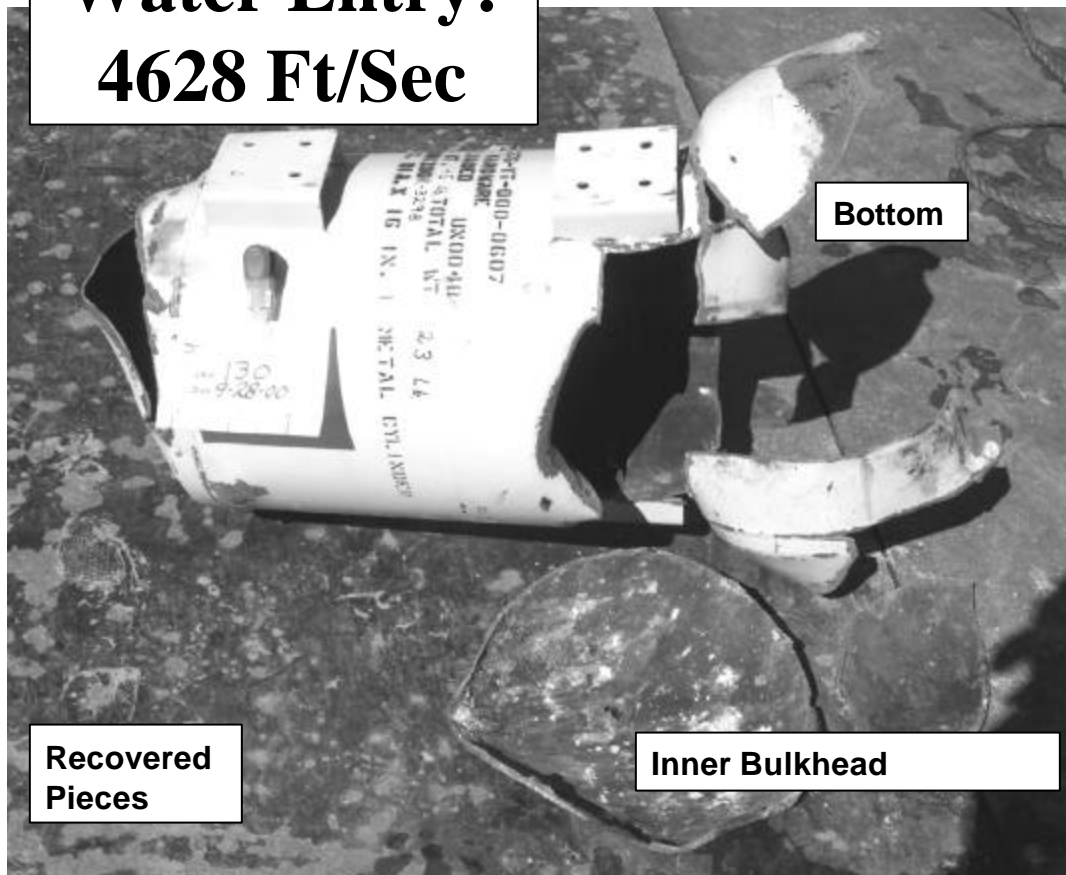
TARGET: Surrogate Mine

NEW: 45 lbs. TNT

Mooring Depth: 25 feet

**30mm
20 Feet Deep**

**Water Entry:
4628 Ft/Sec**



Other Aberdeen Test Results & Observations

- Seventy 30mm Rounds Fired
 - Very Consistent Drag
- Underwater Dispersion
 - 0.70 To 1.4 Milliradians (1σ Radius)
- Demonstrated 5-Round Bursts Into Water
- Long-Rods Are Robust Hydroballistic Designs
 - Nose Material
 - Spin/Yaw
- Established Lethal Depth Capability

Summary



**Water Entry
> 4600 Ft/sec**



**Improved
Projectile
Designs**



**Accurate Target Hits from
75' Slant Range**



**Destruction of
Surrogate Target**

Shot 130

September 28, 2000
Aberdeen Test Center